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RESEARCH MEMORANDUM

INVESTIGATION OF THE AERODYNAMIC AND ICING CHARACTERISTICS OF A RECESSED FUEL CELL VENT ASSEMBLY

I - REAR WALL VENT TUBE MOUNTING

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Investigations have been conducted in the NACA Cleveland icing research tunnel on a ramp type recessed fuel cell vent assembly to determine the aerodynamic, rain, and icing characteristics of such an installation. Vent-tube static-pressure differentials and pressure surveys over the vent ramp were obtained as a function of angle of attack and tunnel-air velocities. The vent tubes were also investigated in a simulated rain condition to determine the amount of water admitted into the vent openings. Icing experiments were made at high angles of attack and at a tunnel-air velocity of 220 feet per second to determine the vent installation icing characteristics and the vent tube pressure and air-flow losses.

The results of the aerodynamic investigation show that, although the vent-tube openings are located in the region of maximum ramp pressure, vent-tube static pressures are marginal for a low flight speed condition comparable to letdown. During the rain experiment, no measurable amount of water was admitted into the vent-tube openings. The vent-tube openings remained relatively ice free under severe icing conditions for icing periods up to 62 minutes. Severe losses in pressure and moderate air-flow losses in the vent tubes were observed during the icing experiments.

INTRODUCTION

In a previous study of ice-free vents consisting of vent tubes facing downstream (reference 1), the fuel-tank pressures were of the order of $-0.1\ q_0$ (where q_0 is the velocity pressure of the air stream). It has been found, however, that negative pressure venting of certain types of fuel cells now in use can cause them to collapse in such a manner that most of their contents are expelled, thereby creating a serious fire hazard. Consideration has also been given to sealing the fuel cell compartment and venting it to the upper wing surface while venting the fuel cell to the lower wing surface by means of a flush vent. This solution, however, is impracticable for many installations.

The present investigation to determine the icing characteristics of a recessed fuel cell vent installation was conducted in the icing research tunnel of the NACA Cleveland laboratory as a part of the general study of aircraft icing.

The recessed vent installation, which is located in the outer wing panel, was designed to replace flush type fuselage and nacelle vents. These flush-type vents were believed to constitute a serious fire hazard under certain operating conditions. The location of the recessed vent is in an area susceptible to icing, particularly during low speed flight, climb, and letdown attitudes. It was therefore necessary to determine whether or not ice formations during normal flight operation could sufficiently reduce the pressure and air flow in the vent tubes to cause failure of the fuel cells.

APPARATUS AND INSTRUMENTATION

An investigation to determine the icing and pressure characteristics of a recessed fuel-cell vent assembly was conducted in the 6- by 9-foot test section of the NACA Cleveland icing research tunnel.

An NACA 65,2-216 airfoil section of 8-foot chord was used as a wing model for the vent installation. (See fig. 1.) The model was equipped with an external electric heater over the leading-edge region back to 20 percent of the chord. Details of the vent are shown in figure 1(b).

The vent recess was so installed that the rear edge of the recess was located at 67 percent of chord on the lower surface of the airfoil section. A plate of chamfered sheet aluminum 1/32-inch thick was installed just aft of the vent tubes to simulate the standard method of assembly. Three tubes $1\frac{1}{4}$ inch in diameter (1, 3, and 4, fig. 1(b)), and one tube 1 inch in diameter (2, fig. 1(b)) were mounted flush on the rear slope of the recess and each tube extended to a common outlet on the upper surface of the airfoil. Valves were placed in the vent lines to control air flow and the flow of air was measured by means of a calibrated orifice installed in each vent tube. In addition to the orifice pressure measurements, one static pressure was measured on the forward surface of each tube 1 inch from the opening and nine surface static-pressure measurements were made as shown in figure 2. All pressure readings were photographically recorded from multiple-tube manometers.

A water trap was installed in one of the $1\frac{1}{4}$-inch tubes for the collection of water in the simulated rain investigation.

Simulated rain and icing conditions were provided by air-atomizing water-spray nozzles placed upstream of the airfoil section.

EXPERIMENTAL TECHNIQUES AND PROCEDURE

Aerodynamic. - In order to determine the aerodynamic characteristics of the vent installation, static-pressure distributions on the vent ramp surface were obtained as well as the static pressures in the entrance of the vent lines. The experiments were conducted with and without air flow through the tubes. The vent pressure characteristics were determined as a function of tunnel-air velocities of 220 and 350 feet per second, and at angles of attack ranging from 0° to 12°. The vent air flow of 0.6 pounds per minute through the large vent tubes simulated air flow through the vent lines for a descent in altitude at the rate of 3000 feet per minute.

Rain. - The amount of water that would be admitted into the vent lines for a simulated-rain condition was determined with a vent air flow of 0.6 pounds per minute through the large vent tubes, a tunnel air velocity of 220 feet per second, an ambient-air temperature of 46° F, and an angle of attack of 14°. The water concentration for this part of the investigation was approximately 4.5 grams per cubic meter and the droplet size was larger than 20 microns.

Icing. - The icing characteristics of the vent installation were determined for angles of attack ranging from 10° to 14° and at a tunnel-air velocity of 180 to 220 feet per second. The icing conditions ranged from a liquid-water concentration of 1.4 to 1.5 grams per cubic meter for an ambient-air temperature range of 0° to 23° F. The droplet size for these experiments was approximately 15 microns, based on volume maximum.

The vent installation was also investigated for a freezing-rain condition at an ambient-air temperature of 23° F, in which the liquid water concentration was 1.8 grams per cubic meter and the droplet size was larger than 20 microns.

RESULTS AND DISCUSSION

During the aerodynamic investigations, the tunnel blocking effect of the wing at high angles of attack seriously affected the reading of the static tube used to obtain tunnel static pressure. As a result, the surface static-pressure coefficients over the vent ramp were considerably different at a tunnel-air velocity of 350 feet per second than at 220 feet per second. Only the low velocity values are therefore presented because of the relatively smaller error for this condition. The data presented herein are not corrected for tunnel-wall effects and blocking.

A minimum positive pressure differential of 2 inches of water between the vent inlet and the fuel cell has been recommended by the Douglas Aircraft Company for satisfactory operation of the fuel cell. This criterion has been used to evaluate the merits of the vent system under investigation. Any reduction of this pressure differential might lead to collapse of the fuel cells under certain operating conditions.

The icing investigation was conducted at extremely high angles of attack in order to expose the vent openings and the vent ramp to the maximum direct water impingement that an aircraft might encounter. Check experiments at lower angles of attack verified that the icing formations were not so severe as those at the high angles and are therefore not included herein.

Aerodynamic. - The variation of pressure distribution over the vent ramp surface and the rear vent wall is presented in figure 3 for various angles of attack. The pressures are presented in terms of the pressure coefficient $\frac{p - p_0}{q_0}$, where p is the surface static pressure, p_0 is the free-stream static pressure, and q_0 is the free-stream velocity pressure. In general, all the local static pressures at the start of the vent ramp are negative, even at an angle of attack of 12°. At the bottom of the ramp the surface pressures are positive at angles of attack greater than 4°. The maximum surface pressure is attained at approximately the center-line location of the vent tubes.

The maximum pressures obtained at the opening of the vent tubes for angles of attack ranging from 0° to 12° are shown in figure 4. The static-pressure differential $p_s - p_0$, where p_s is the static pressure measured 1 inch from the tube opening, is plotted in figure 4 for the condition of no vent flow. The vent-tube pressure increases rapidly with increasing angles of attack. For the high tunnel-air velocity, the pressure differential reaches a maximum at an angle of attack of 12°. The effect of tunnel blocking by the wing at high angles of attack is illustrated by the peak in the curve at approximately 12°. The low velocity curve does not show this tendency for the angles of attack shown; however, at angles of attack greater than 12°, the same peak effect and subsequent pressure reductions were observed.

The marginal vent pressure condition of 2 inches of water positive pressure is seen to be reached at an angle of attack of 8° for a tunnel-air velocity of 220 feet per second and at an angle of attack of approximately 5° for a tunnel-air velocity of 350 feet per second. On the basis of these observations, it seems probable that the vent installation is extremely marginal in its aerodynamic characteristics.

Rain. - The vent ramp was completely wetted by water run back from the wing surface. However, just upstream of the vent tube openings the water tended to diverge and flow into the corners of the recessed vent installation. From these areas the water was observed to run back or blow off from the surfaces. A 30-minute simulated-rain investigation showed that no measurable amount of water was collected in the vent tube instrumented with a water trap.

Icing. - In general, the icing investigation of the recessed vent installation showed that the vent lines remained relatively free of ice formations, although the vent air flow and the static pressure in the vent lines were reduced. On an over-all basis, the vent installation surfaces were coated with a light ice formation. The vent ramp was severely iced only at the upstream end. Considerable ice formations accreted to the rear slope of the vent installation from above the tubes to the wing surface. The chamfered plate representing the actual wing-skin installation contributed slightly to the forward and outward growth of the ice formations at the rear of the vent. Ice formations in the vent tubes started to build up as frost formations on the downstream side of the tubes because this area of the tubes was more susceptible to the direct impingement of small water droplets. For long icing periods in the order of 30 minutes or more, the entire inside of the vent tubes were coated with a very light ice formation that extended approximately 3 diameters into the tube.

Photographs of the typical progressive formation of ice on the vent installation are shown in figure 5. The icing conditions for this part of the investigation were as follows: tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; and liquid-water content, 1.5 grams per cubic meter. The air flow through the vents at the beginning of the icing period was 0.605 pounds per minute. At the end of 15 minutes (fig. 5(a)), only a light ice formation was observed on the vent ramp and frost formations were seen in the vent tubes. At the rear of the vent installation, a ridge of ice approximately 1/2-inch thick was built up near the wing surface. These formations of ice, particularly at the rear edge of the vent recess, increased in size and extent as the icing period was increased (figs. 5(b) and 5(c)). The reduction in the vent-tube diameters due to icing was small.

Occasionally the growth of ice at the rear of the vent installation protruded into the air stream to such an extent that a scoop effect was obtained, as shown in figure 5(b). This ice formation increased the ram pressure in the top vent tube by almost 100 percent.

For the icing conditions investigated, the air flow through the vent tubes and the static pressure in the vent tubes were reduced with progressive icing. These losses were due to the rough ice formations on the wing surface upstream of the vent ramp, light ice formations on the vent ramp, and frost formations inside the vent tubes. The fact that the upstream orifice static pressure and the vent-tube static pressure gave identical readings under all icing conditions indicates that the vent tube static-pressure openings did not ice. The variation of vent-tube static pressure and air flow with time, for the icing conditions shown in figure 5, is presented in figures 6 and 7. The vent-tube static pressure is shown plotted as a pressure differential $(p_s - p_0)$, where p_s is the static pressure measured 1 inch from the tube opening. In general, the static pressure decreased rapidly with time during the icing period. It can be seen in figure 6 that the required 2-inch pressure differential between the fuel cell and the vent opening is marginal after only 2 to 3 minutes of icing for the large vent tubes and marginal for the smaller vent tube (2) under a non-icing condition. The pressure differential in all the tubes increased after the leading edge of the wing had been completely de-iced during the tunnel shutdown for photographs and observations at the end of 15 minutes of icing (point A). The increase in pressure differential in vent tubes 1 and 2 in the 15- to 30-minute time interval is accounted for by the scooping effect of the ice formations as described in figure 5. During the tunnel shutdown at the end of 30 minutes, the tunnel-air temperature was inadvertently raised above the freezing point and some of the formations were blown off the wing and vent surfaces when the tunnel was restarted. The reduction of the ice formations thus accounts for the abrupt changes in vent-tube pressure differential shown to occur at point B on figure 6. A scooping effect of the ice formations is again noted for vent tube 1 near the end of the icing period. (See fig. 5(c).)

The variation of vent air flow with time during an icing period is shown in figure 7. The figure shows a typical reduction in air flow through the vent tube with time for the same icing conditions as described for figure 5. After the leading edge of the wing had been de-iced to 20 percent of chord, the air flow through the vents was increased as shown by point A in figure 7. The importance of maintaining the leading edge of the wing ice free to insure maximum pressure differential and adequate vent air flow therefore has a great effect on the proper functioning of a recessed vent installation. The partial removal of surface ice formations (point B) also had the effect of increasing the air flow through the vent tubes by reducing the blocking upstream of the vent openings and by reducing the turbulent condition of the air flow over the wing and vent surfaces.

Pressure and air flow losses observed during the freezing rain experiment were approximately the same as those experienced under the icing conditions.

SUMMARY OF RESULTS

The following results were obtained from an icing research tunnel investigation of a recessed fuel-cell vent installation designed to replace flush-type fuselage and nacelle vents:

1. The results of the aerodynamic investigation show that the pressures at the vent tubes are marginal for the let-down flight condition. Surface pressure surveys indicate that the vent tubes are located in the area of greatest pressure on the ramp.

2. There was no indication of water collecting in the vent tubes during the simulated-rain investigation.

3. The recessed fuel-cell vent tubes remained relatively ice free for angles of attack up to 14° under severe icing and freezing rain conditions of 30- to 62-minute duration.

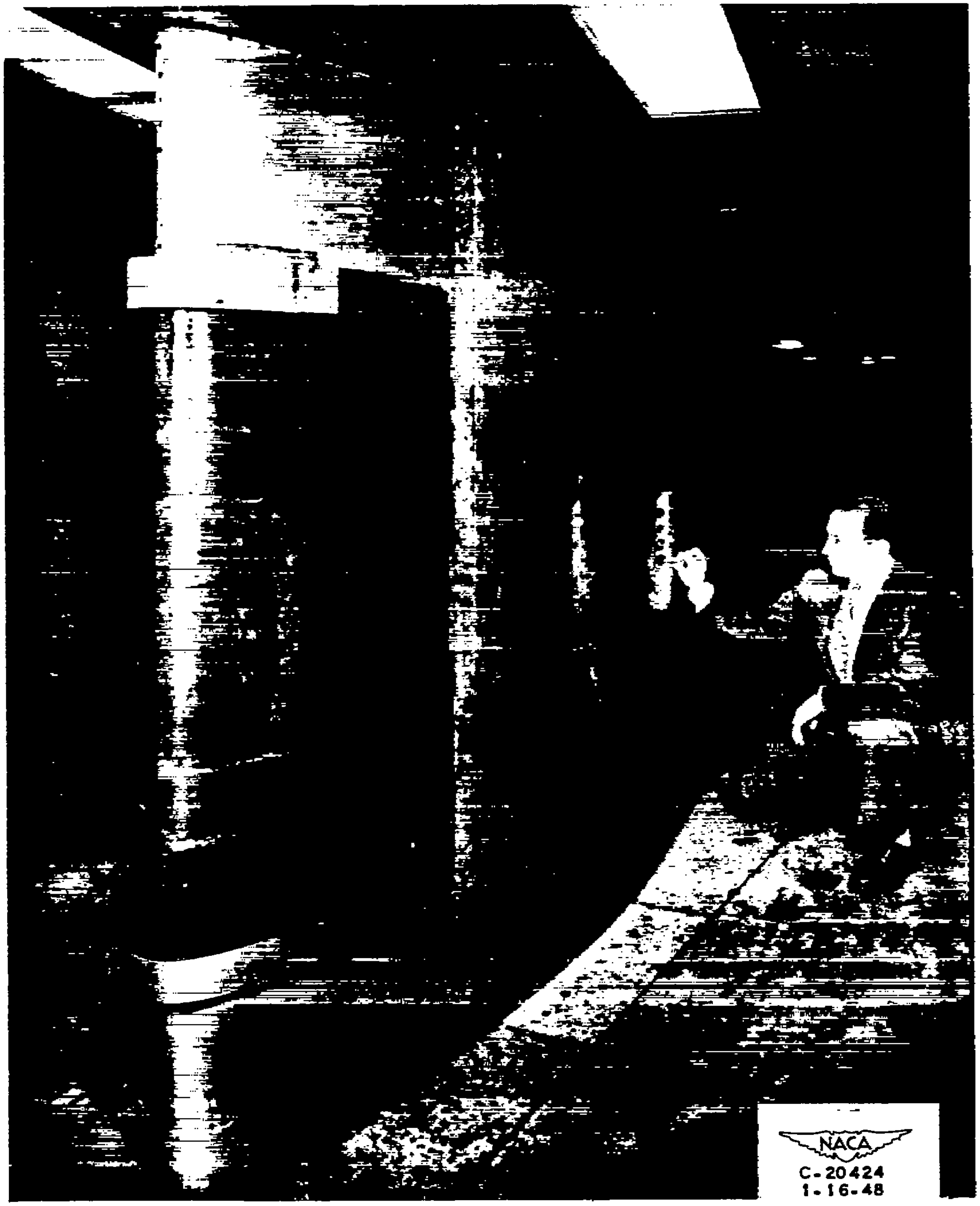
4. Severe and rapid losses in the vent-tube static pressure were recorded under icing conditions of 1.5 grams per cubic meter, a droplet size of 15 microns, an angle of attack of 14°, and a tunnel-air velocity of 220 feet per second. The marginal vent-tube pressure differential of 2 inches of water was reached after only 2 to 3 minutes of icing under the above conditions.

5. The vent-tube air flow is decreased slightly by the general icing characteristics of the wing and vent installation.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, January 27, 1948.

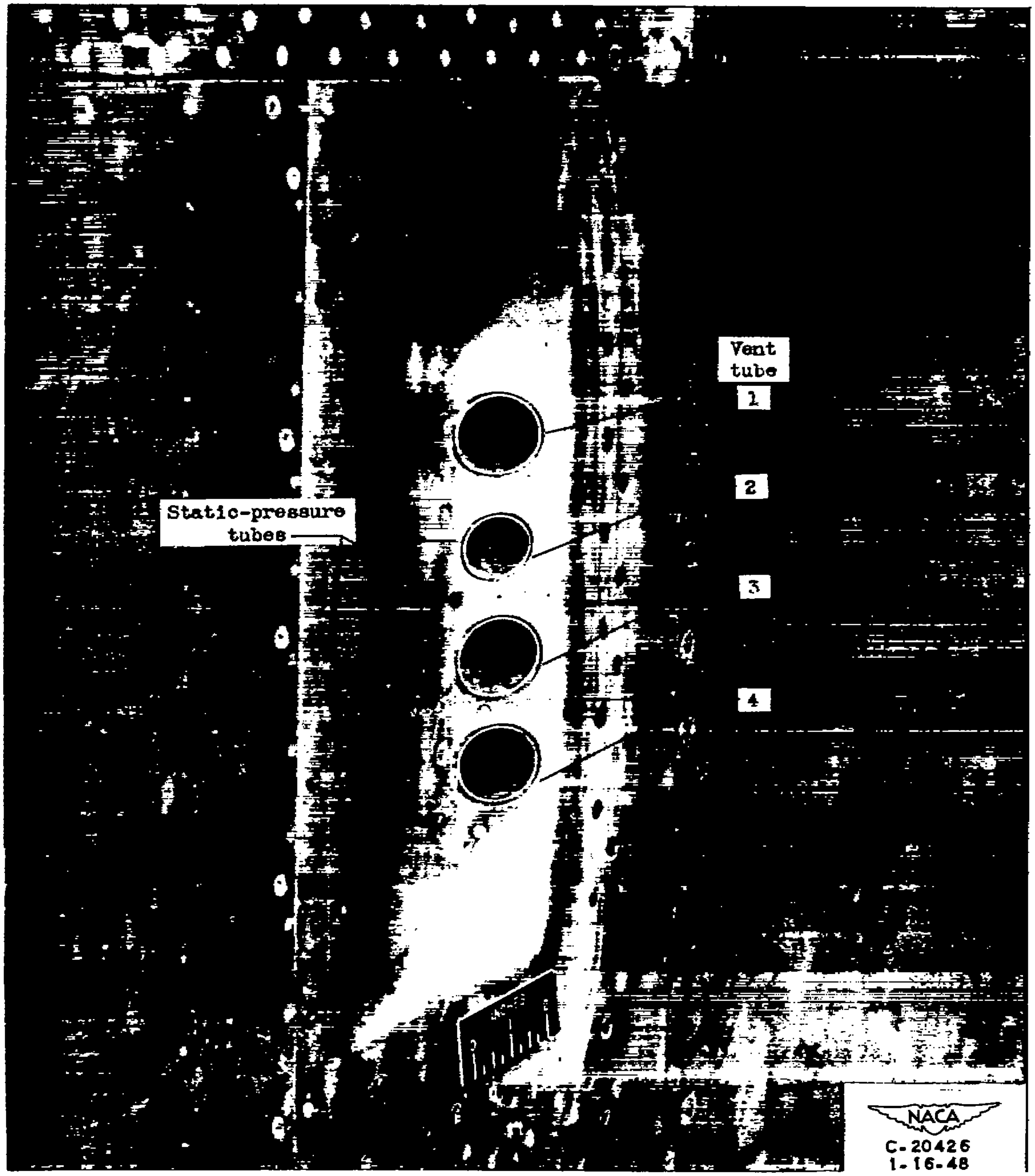
REFERENCE

1. Theodorsen, Theodore, and Clay, William C.: The Prevention of Ice Formation on Gasoline Tank Vents. NACA TN No. 394, 1931.



(a) Vent assembly located on lower wing surface.

Figure 1. - Recessed fuel tank vent assembly installed on NACA 65,2-216 airfoil section in Icing Research Tunnel.



(b) Close-up view of vent installation.

Figure 1. - Concluded. Recessed fuel tank vent assembly installed on NACA 65,2-216 airfoil section in Icing Research Tunnel.

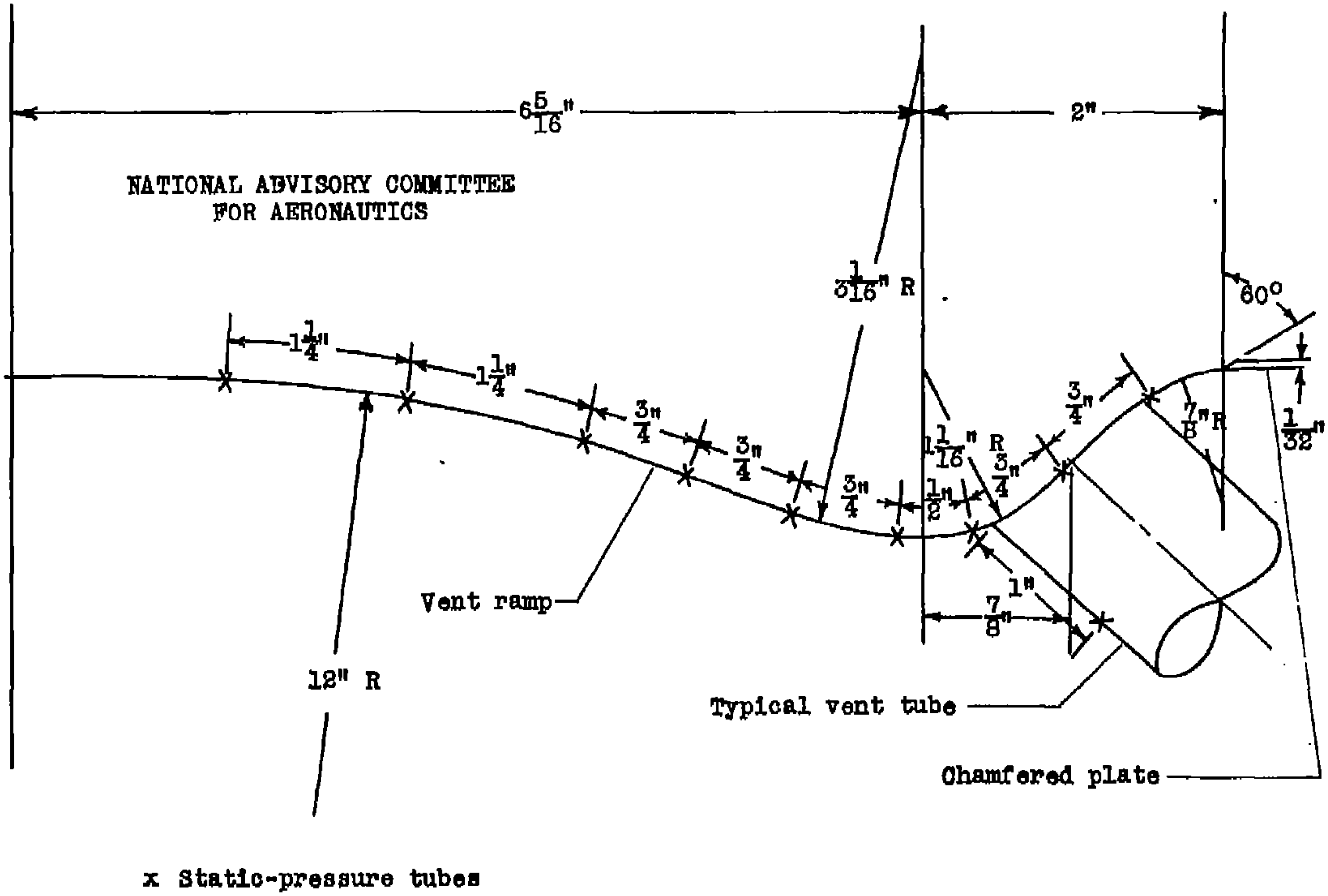


Figure 2. - Schematic drawing of fuel-tank vent assembly showing locations of static-pressure tubes.

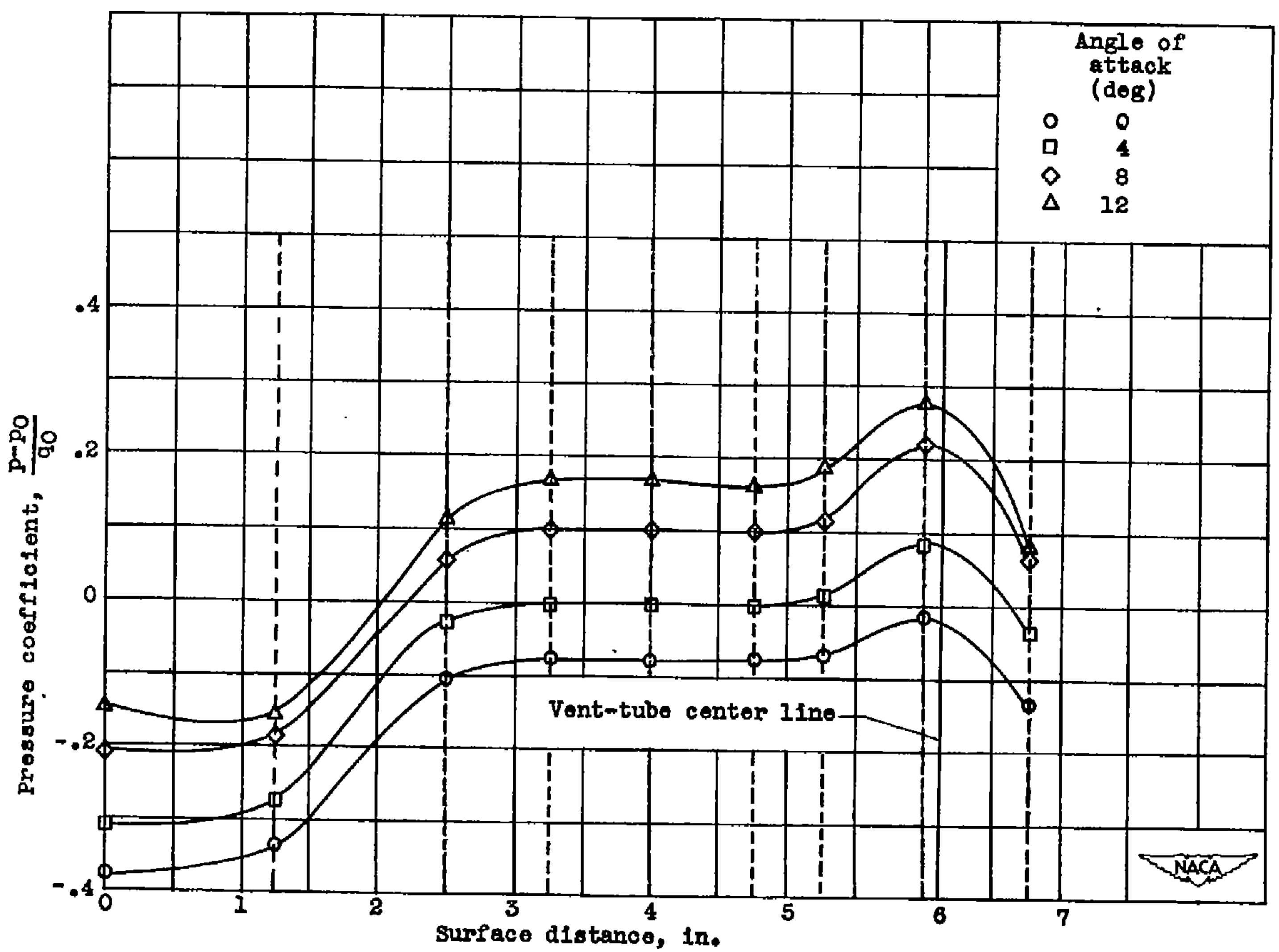


Figure 3. - Effect of angle of attack on pressure distribution over fuel-cell vent ramp surface. No vent air flow; tunnel-air velocity, 220 feet per second.

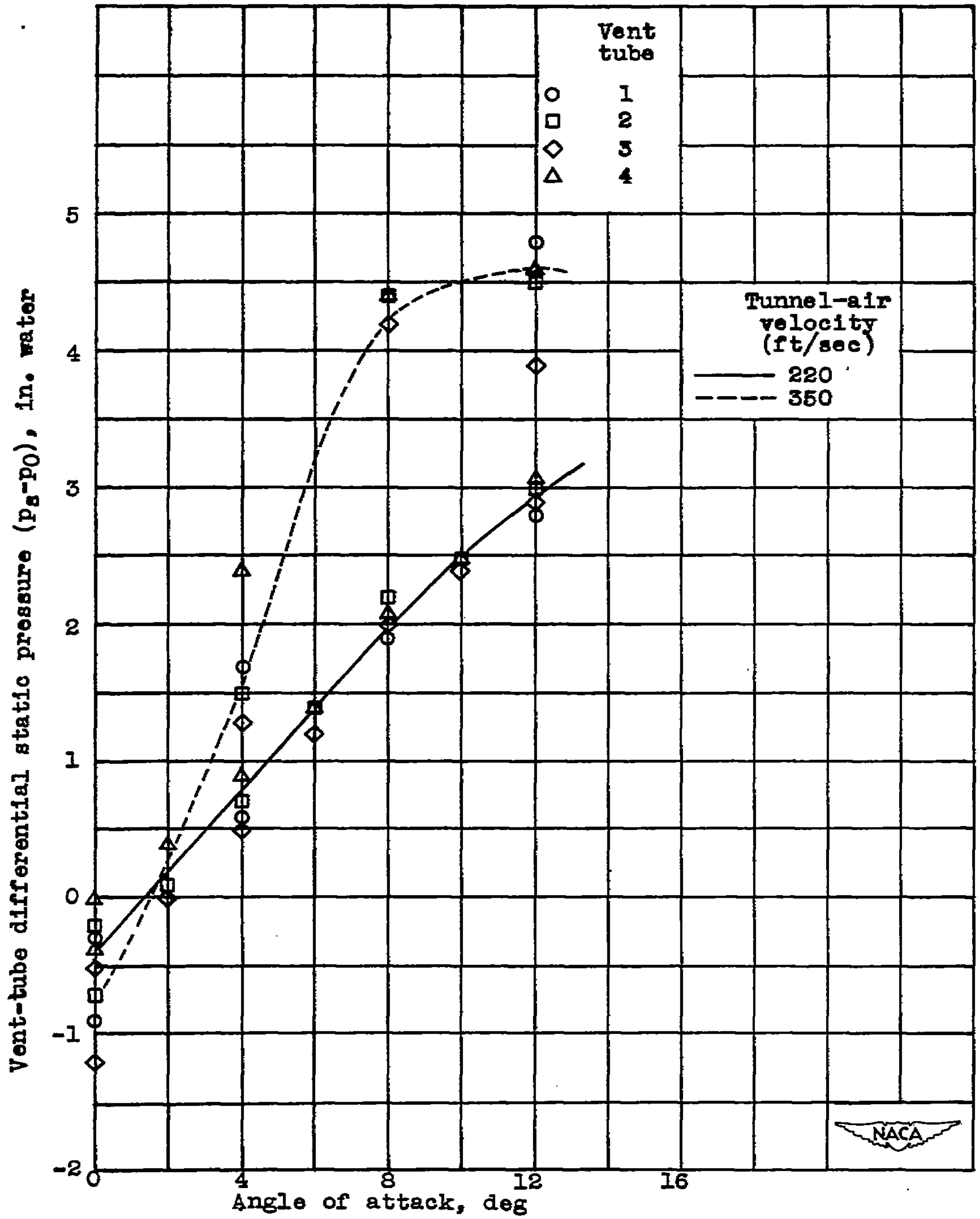
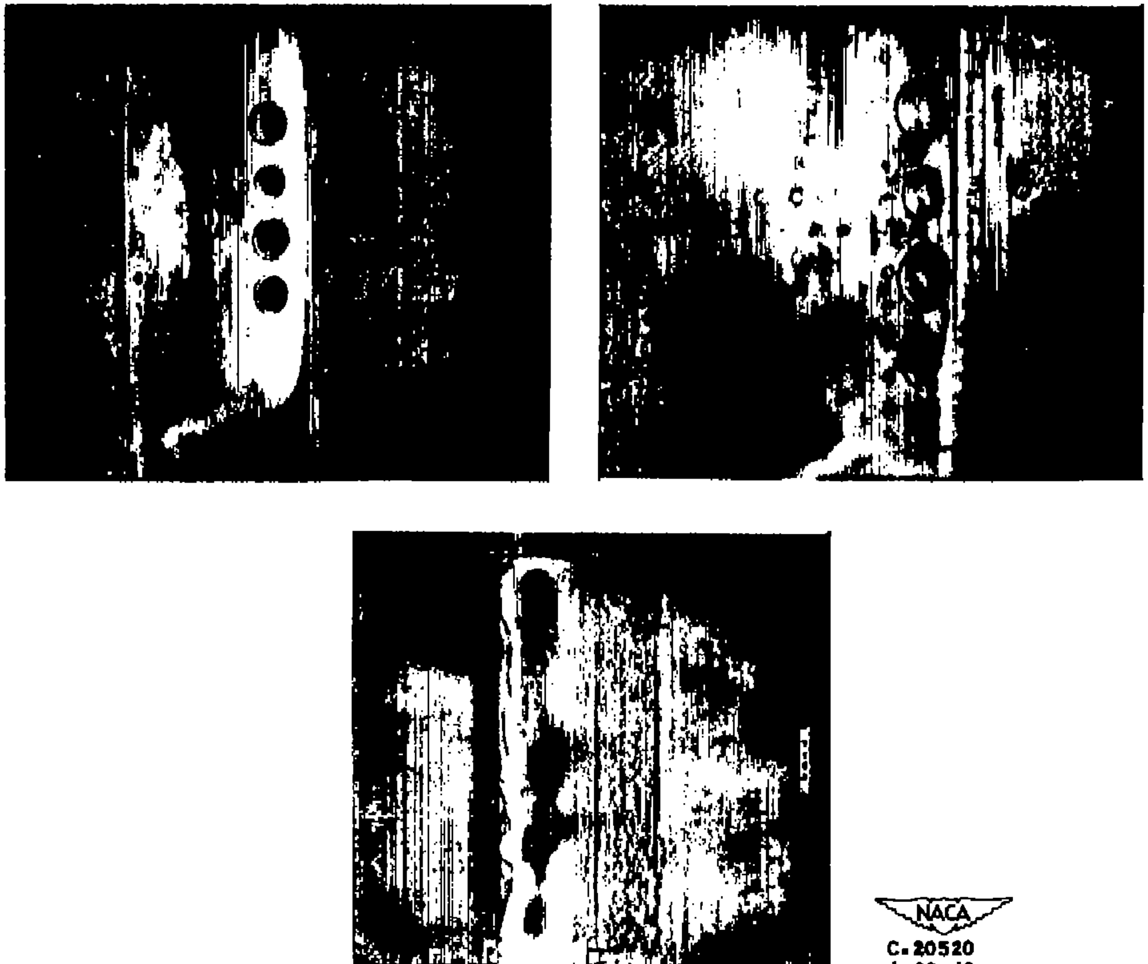


Figure 4. - Variation of vent-tube differential static pressure with angle of attack. No vent air flow.



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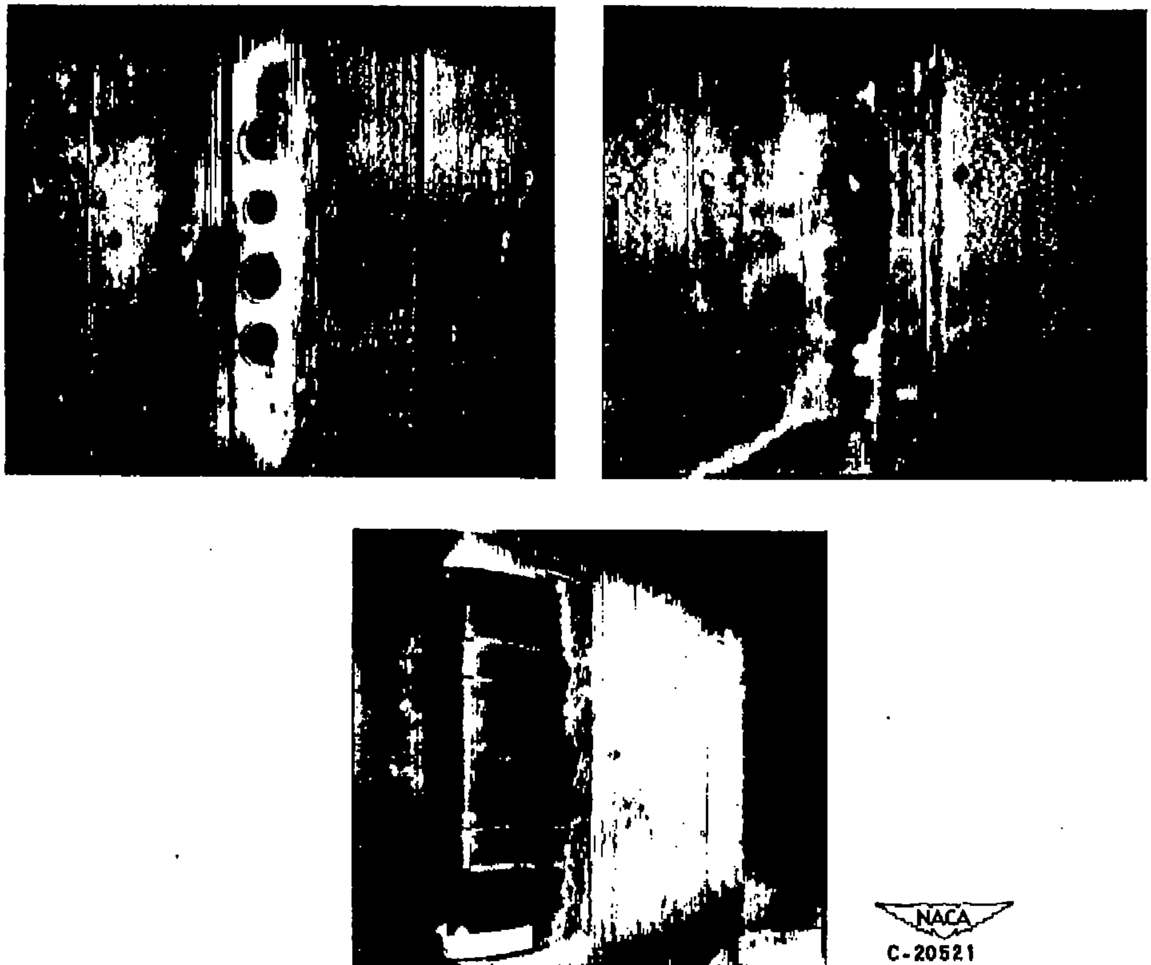
(a) Ice accretions following 15-minute icing period; wing leading edge unheated.

Figure 5. - Photographs of ice on airfoil and at vent recess. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid water content, 1.5 grams per cubic meter.



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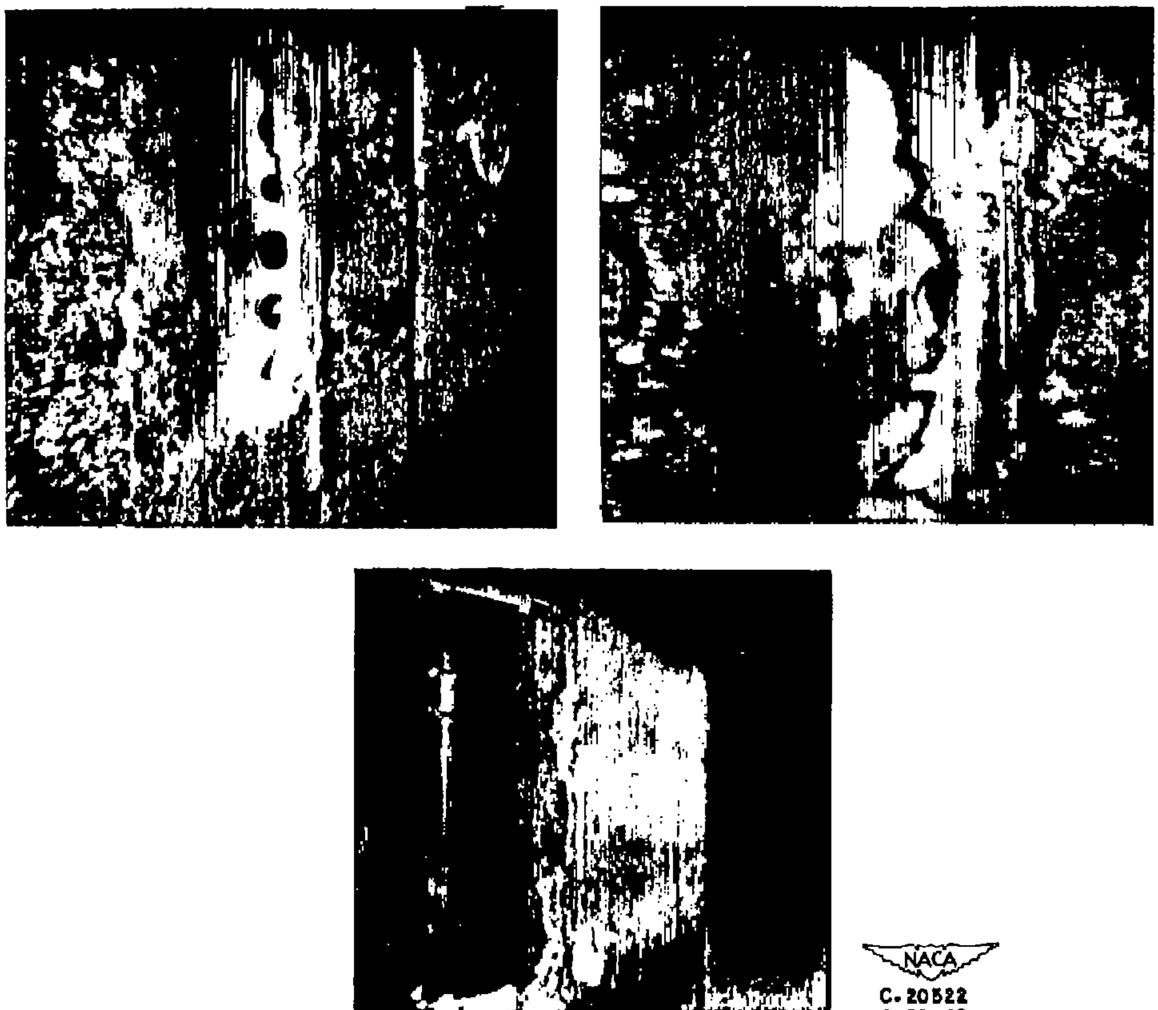
(b) Ice accretions following 30-minute icing period; wing leading edge heated to 10 percent chord.

Figure 5. - Continued. Photographs of ice on airfoil and at vent recess. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid water content, 1.5 grams per cubic meter.



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(c) Ice accretions following 62-minute icing period; wing leading edge heated to 10 percent chord.

Figure 5. - Concluded. Photographs of ice on airfoil and at vent recess. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid water content, 1.5 grams per cubic meter.

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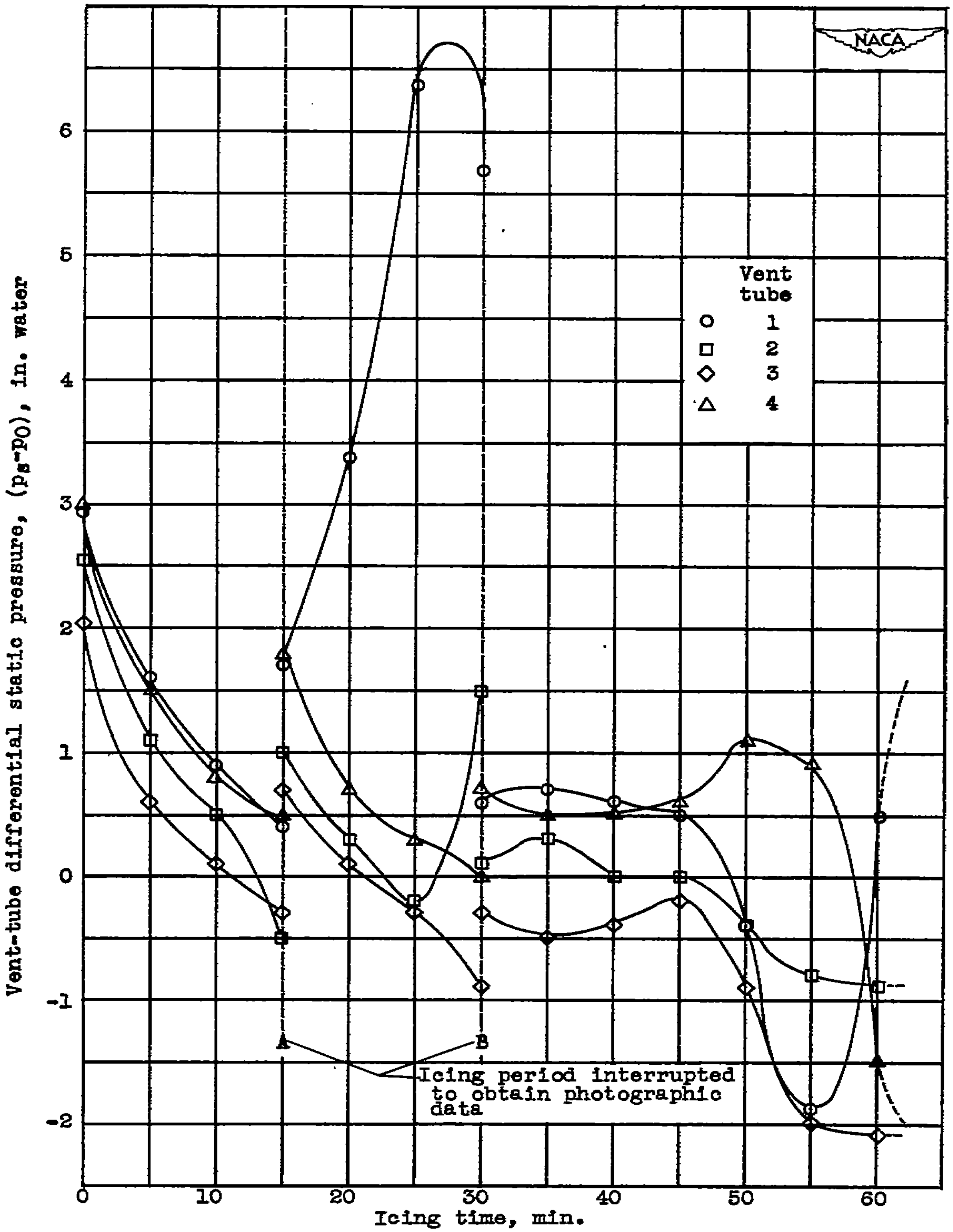

Figure 6. - Variation of vent-tube differential static pressure with icing time for 62-minute icing period. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, 1.5 grams per cubic meter.

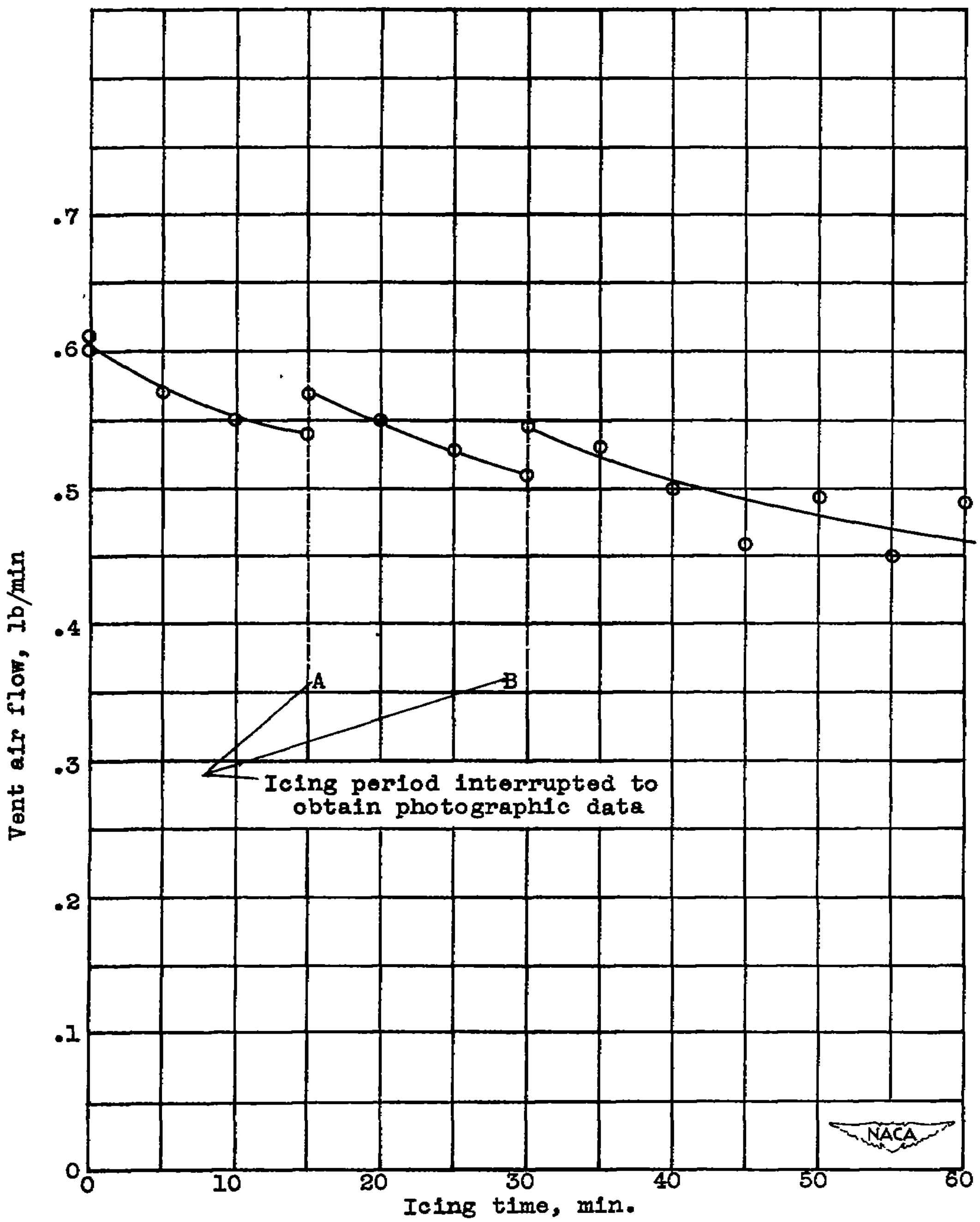

Figure 7. - Variation of typical vent air flow (vent tube 3) with icing time for 62-minute icing period. Tunnel-air velocity, 220 feet per second; angle of attack, 14°; ambient-air temperature, 23° F; liquid-water content, 1.5 grams per cubic meter.